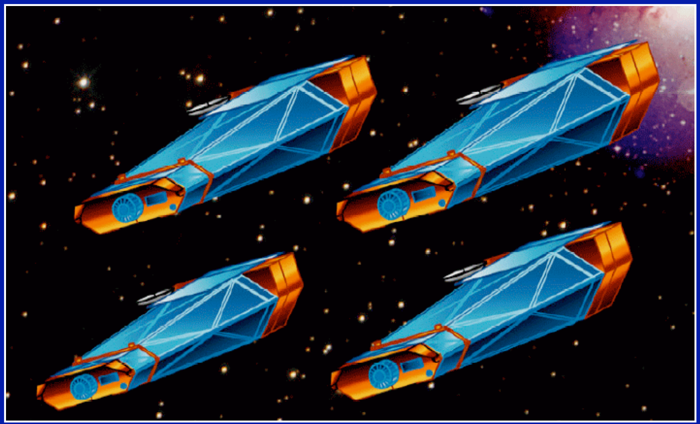
Formation and Evolution of SMBHs and Their Relationships to Host Galaxies

Reviewer: Niel Brandt (Penn State)



1. X-ray studies of AGNs at the highest redshifts (z > 4).
2. X-ray AGNs in distant submillimeter galaxies.
3. X-ray observations of (possible) relativistic outflows from luminous quasars.

X-ray Studies of AGNs at the Highest Redshifts

Are early black holes feeding and growing in the same way as local ones?

X-rays probe the black-hole region. Known to change with accretion rate.

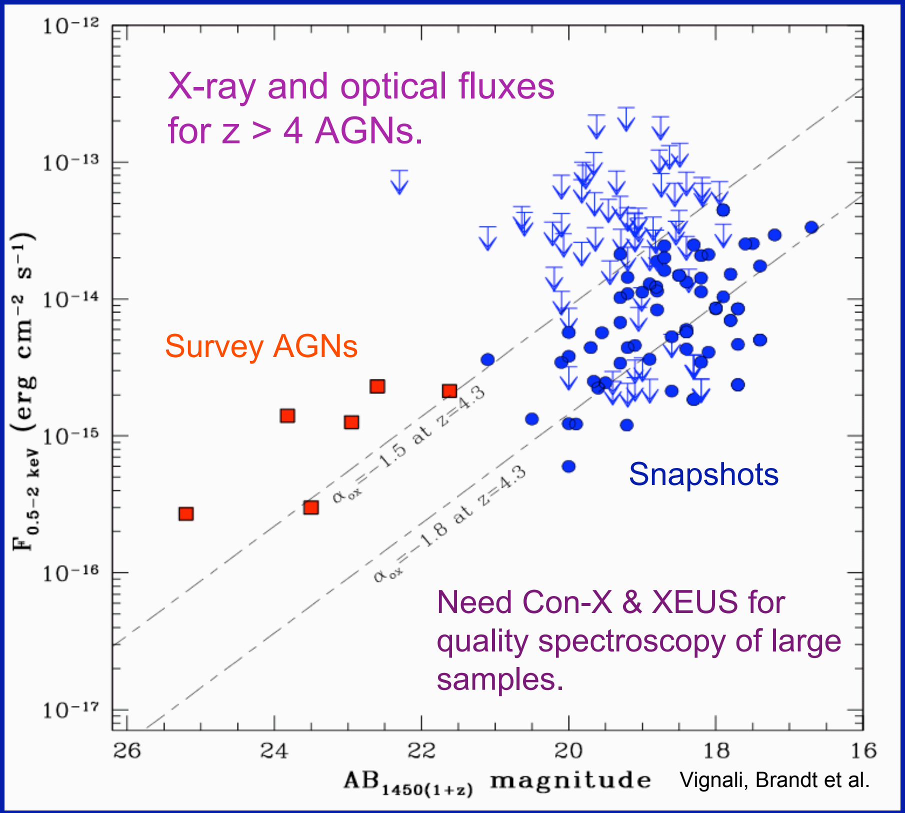
Plausibly different (number density changes, large masses acquired fast).

Environments of high-redshift AGN (e.g. X-ray absorption).

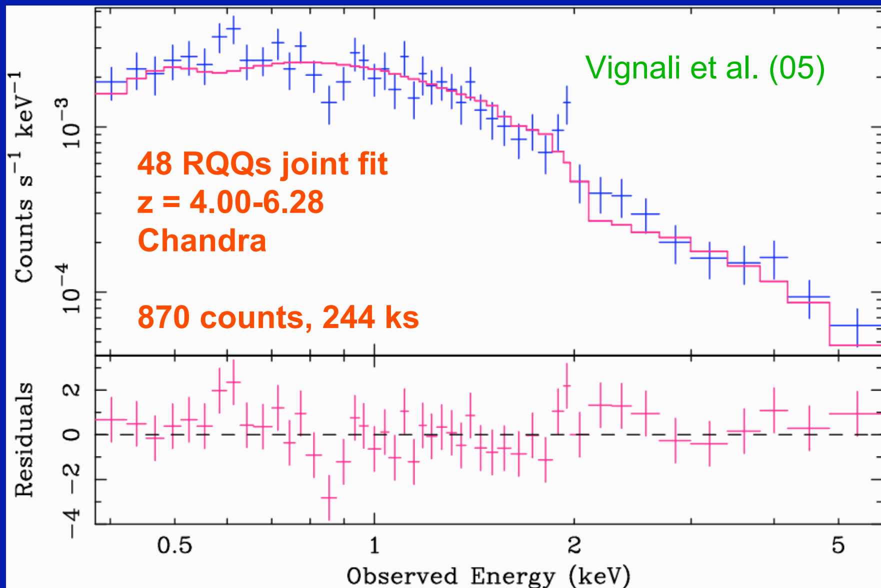
High-redshift AGN demography.

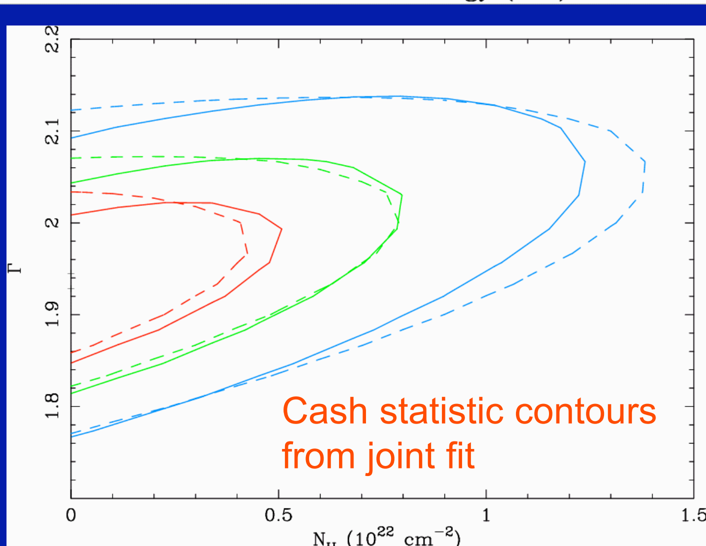
1. Chandra 4-12 ks "snapshots" (SDSS, PSS, RLQs, Exotics).
2. XMM-Newton spectroscopy.
3. Deep and medium-deep X-ray surveys.
4. Archival data for supporting samples.

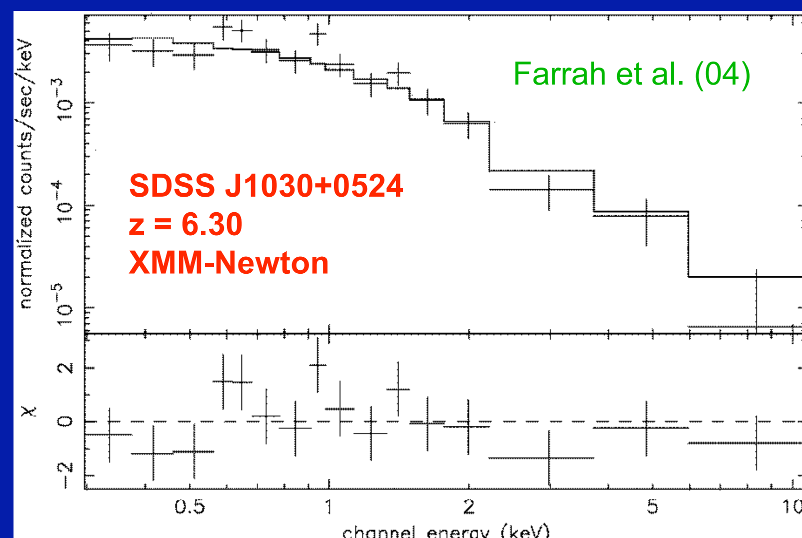
Now have ~ 100 X-ray detections at z > 4.



Joint Fitting and Single-Object X-ray Spectroscopy at z > 4







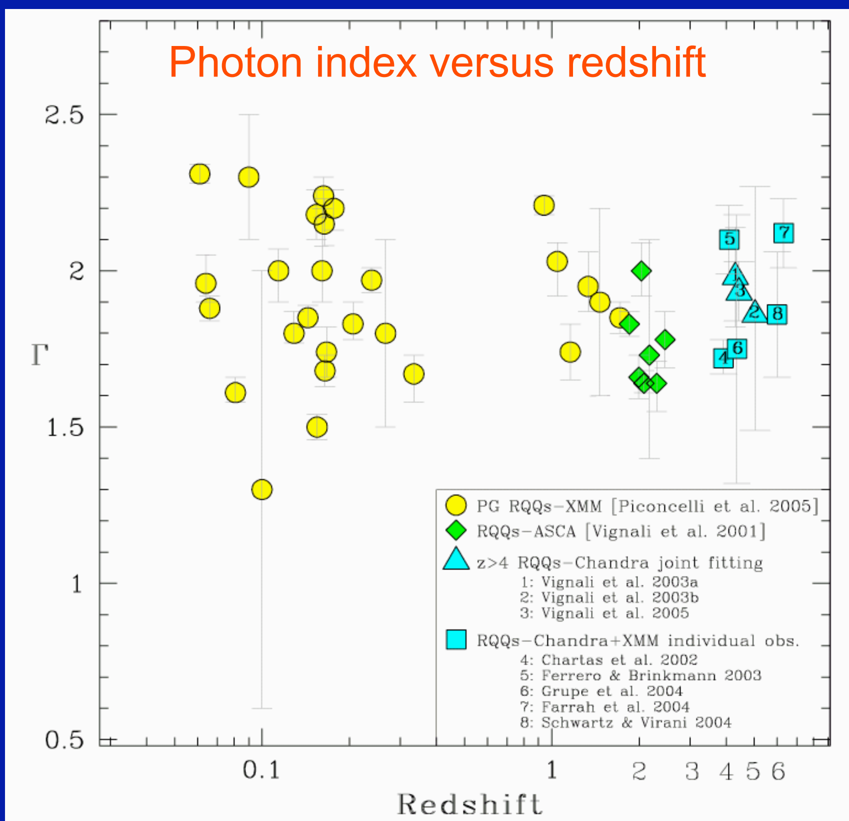
Also see Ferrero et al. (03), Grupe et al. (05), Schwartz & Virani (05).

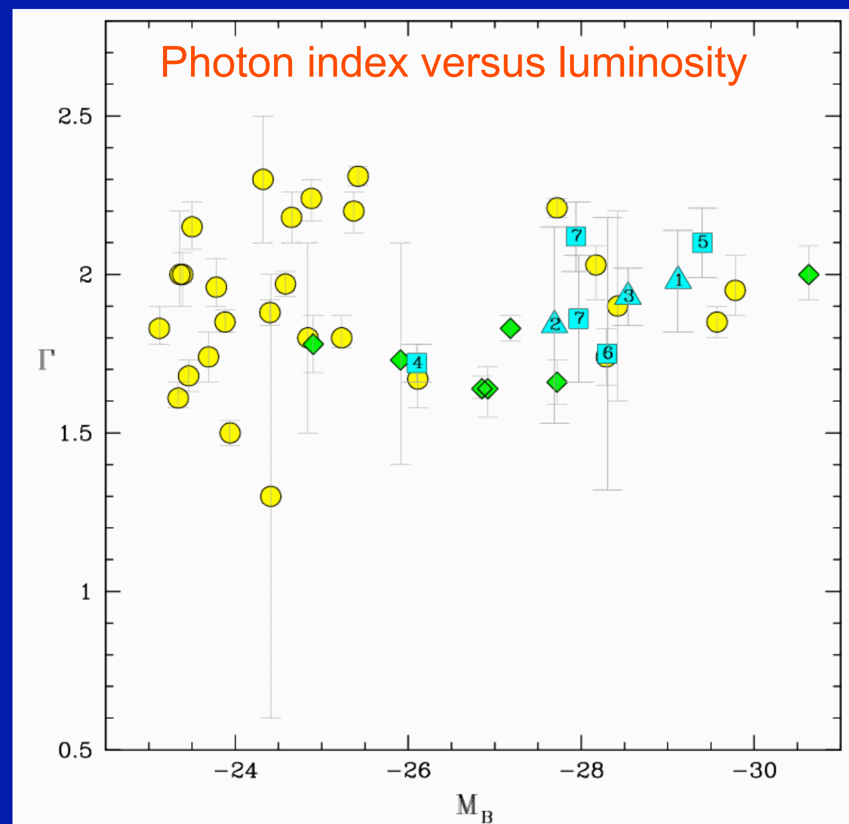
X-ray Spectral Comparisons at Low and High Redshifts

Power-law models give acceptable fits – photon index shows object-to-object intrinsic scatter that remains poorly understood, but no systematic change.

No X-ray absorption detected at “fingernail” level from luminous RQQs (compare RLQs).

No iron K line or X-ray reflection “hump” detected – expected for highly luminous objects.





X-ray Contribution to Spectral Energy Distribution

Dependence of α_{ox} upon luminosity and redshift.

Investigated since the 1980's, but still debated today as our knowledge of AGNs is refined.

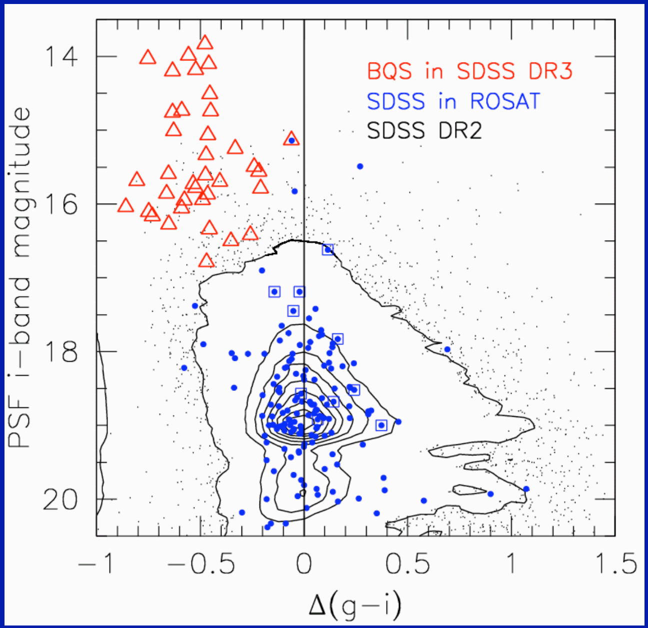
Tough problem with thorny issues involved.

1. Initial sample quality. Coverage of luminosity and redshift.
2. High fraction of X-ray detections and good statistical tools.
3. Absorbed AGN removal/control and RQQ/RLQ separation.
4. High-quality photometry in optical/UV with host-galaxy removal.

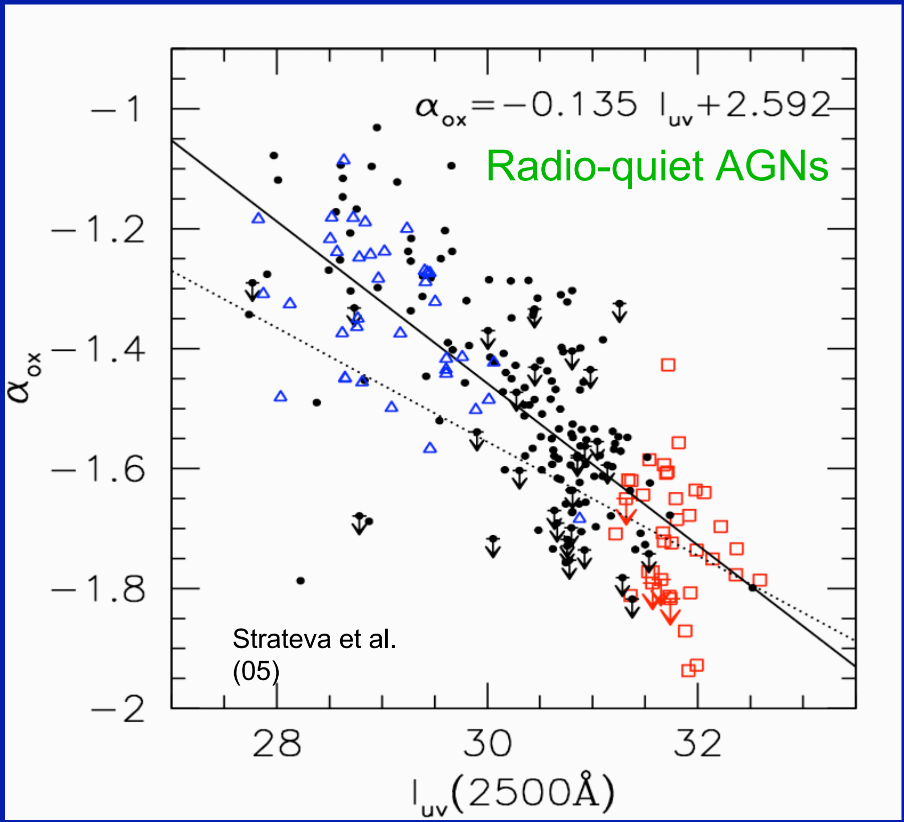
Strateva et al. (05) have just finished detailed study, using a sample of 229 AGNs mainly from SDSS.

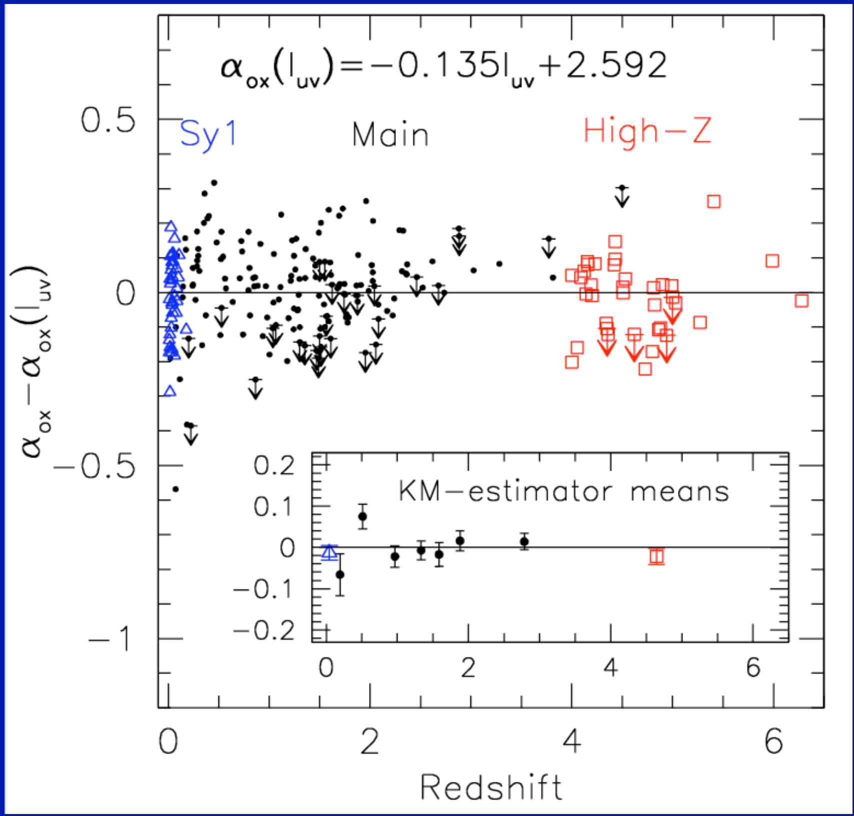
Representative of SDSS AGNs as a whole.

Redder colors than BQS AGNs.



X-ray Contribution to Spectral Energy Distribution





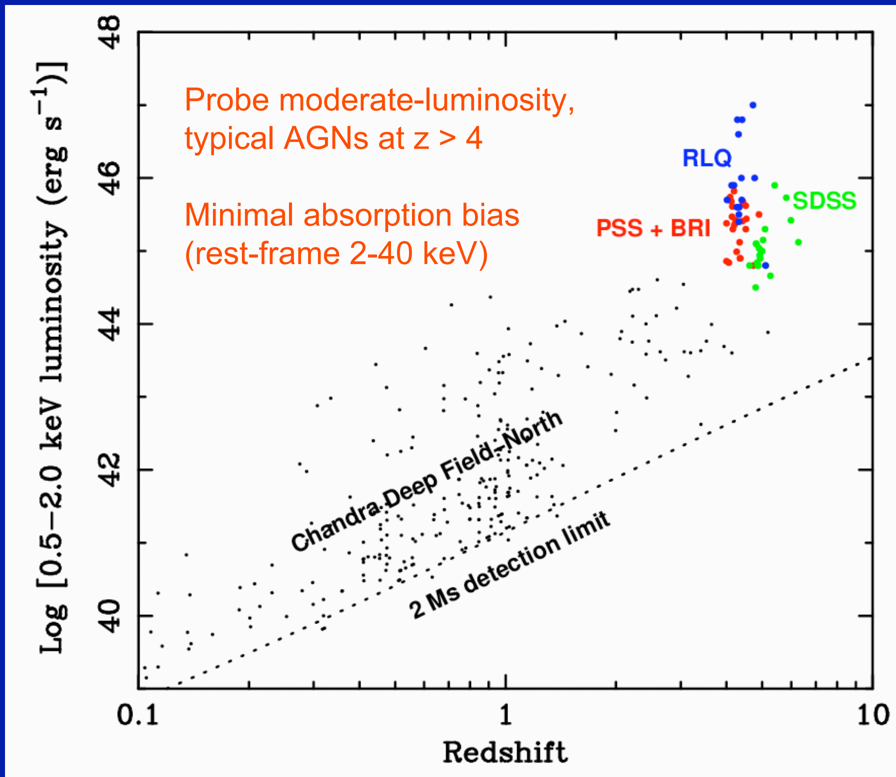
Partial correlation analyses indicate luminosity effect is primary (7.5-10.7 sigma). Qualitatively consistent with most earlier work, but quantitatively somewhat different.

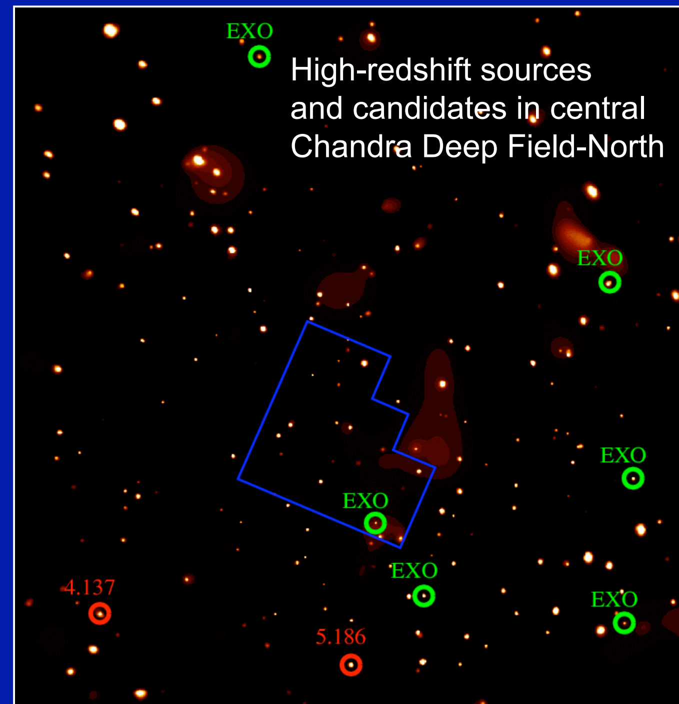
No detected redshift effect (< 1.1 sigma). Tightest constraints to date derived: 20% from z ~ 0-5.

Useful for X-ray flux prediction, “special” AGN studies, disk + corona models, bolometric corrections, etc.

Separate studies of 12 RLQs at z ~ 4 indicate that their jet-linked X-ray components do not change. Also no X-ray bright IC/CMB jets detected (maybe ~ 2 weak jets).

X-ray Survey Constraints on z > 4 AGNs





Find or constrain sky density exploiting Lyman break.

Alexander et al. (01), Barger et al. (03), Cristiani et al. (04), Koekemoer et al. (04)

Eight X-ray selected, moderate-luminosity AGNs now discovered at z > 4, and number growing fast.

Sky density is ~ 30-150 deg^{-2}. AGN contribution to reionization at z ~ 6 was small.

X-ray photon indices and broad-band SEDs appear consistent.

Table 1. Moderate-luminosity $z > 4$ AGNs found in X-ray surveys

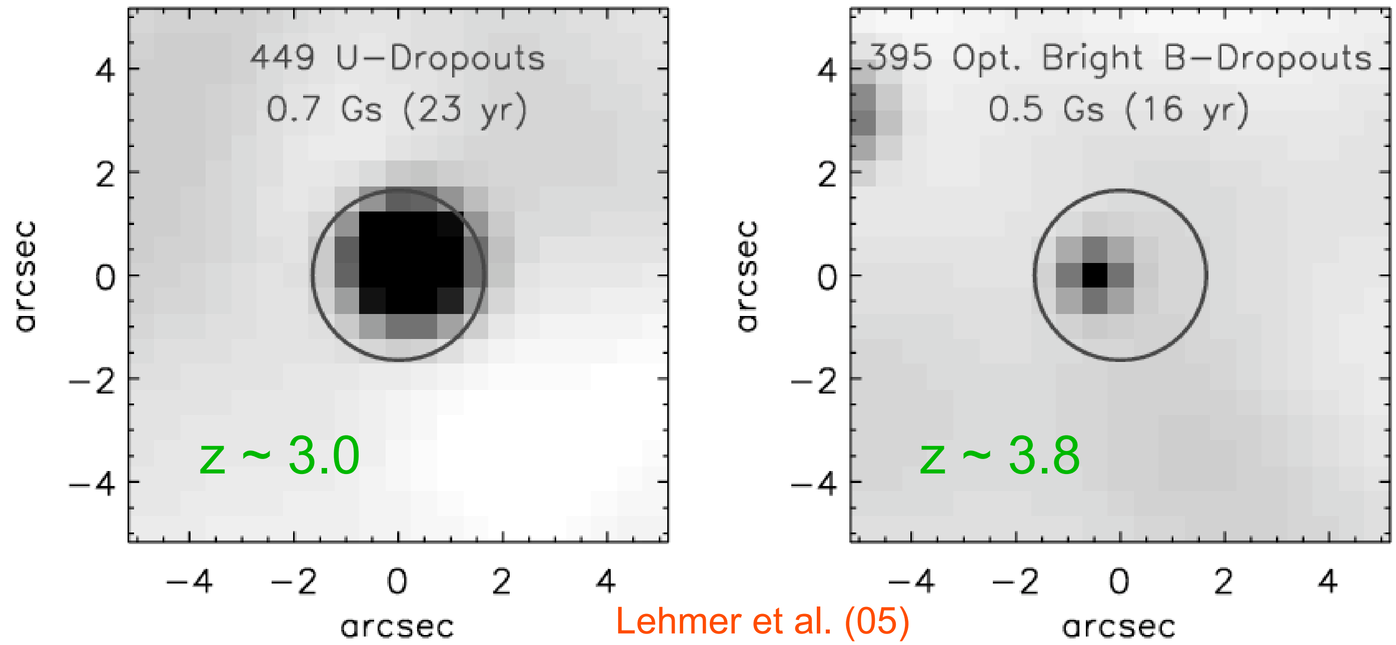
AGN name	Redshift	Rest-frame $\log(L_{2-10})$	Representative reference
CXOCY J033716.7 − 050153	4.61	44.54	Treister et al. (2004)
CLASXS J103414.33+572227	5.40	44.44	Steffen et al. (2004)
RX J1052 + 5719	4.45	44.72	Schneider et al. (1998)
CXOMP J105655.1 − 034322	4.05	44.92	Silverman et al. (2005)
CXOHDFN J123647.9 + 620941	5.19	44.00	Vignali et al. (2002)
CXOHDFN J123719.0 + 621025	4.14	43.72	Vignali et al. (2002)
CXOCY J125304.0 − 090737	4.18	44.39	Castander et al. (2003)
CXOMP J213945.0 − 234655	4.93	44.79	Silverman et al. (2002)

The third column above is the rest-frame 2–10 keV luminosity (in erg s^{-1}), computed using a power-law photon index of $\Gamma = 2$. We have only included AGNs in this table with $\log(L_{2-10}) < 45$. A few higher luminosity AGNs have also been found in X-ray surveys, such as RX J1028.6−0844 (Zickgraf et al. 1997) and RX J1759.4+6638 (Henry et al. 1994).

Constraining Lower Luminosity AGNs at High Redshift

X-ray Stacking of Large Lyman Break Galaxy Samples from GOODS-N + GOODS-S

Note the impressive effective exposure times!



Lehmer et al. (05)

Also tight constraints on V, i dropouts at z ~ 5, 6

Observed X-ray emission plausibly from X-ray binaries and supernova remnants – no need to invoke numerous lower luminosity AGNs.

Also see Wang et al. (04) for Lyman alpha emitters at z ~ 4.5

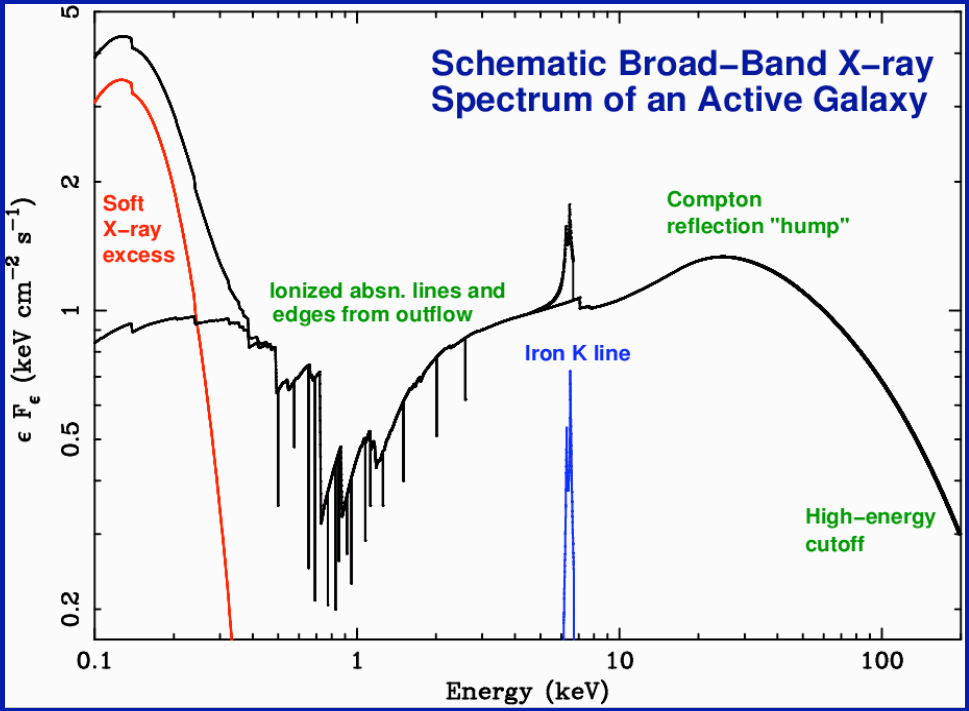
Prospects for Constellation-X and XEUS - 1

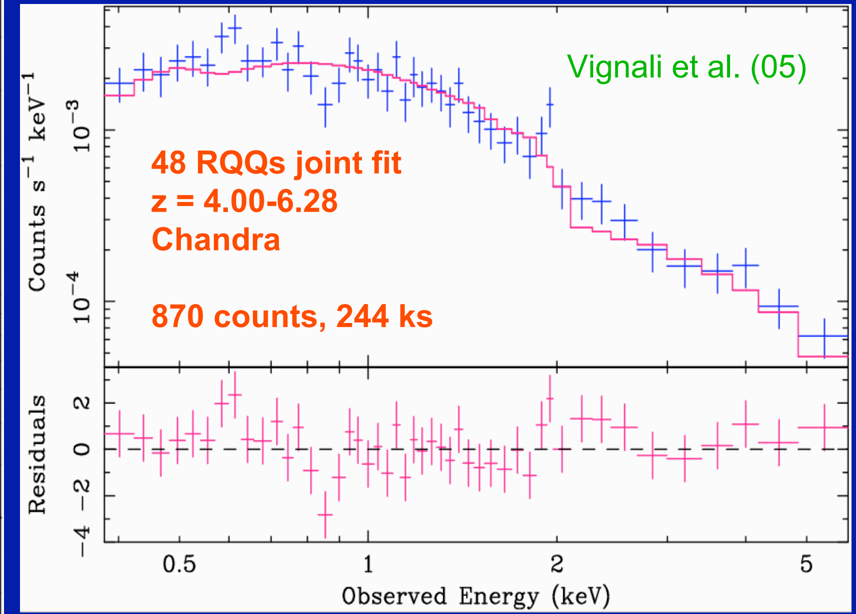
X-ray spectral and SED analyses indicate that, to first order, AGN X-ray continuum emission does not change significantly with redshift.

No evidence for changes in accretion mode due to accretion-rate changes.

For Constellation-X and XEUS this is reassuring. Local AGN studies may be generally applicable, at least in terms of their intrinsic emission.

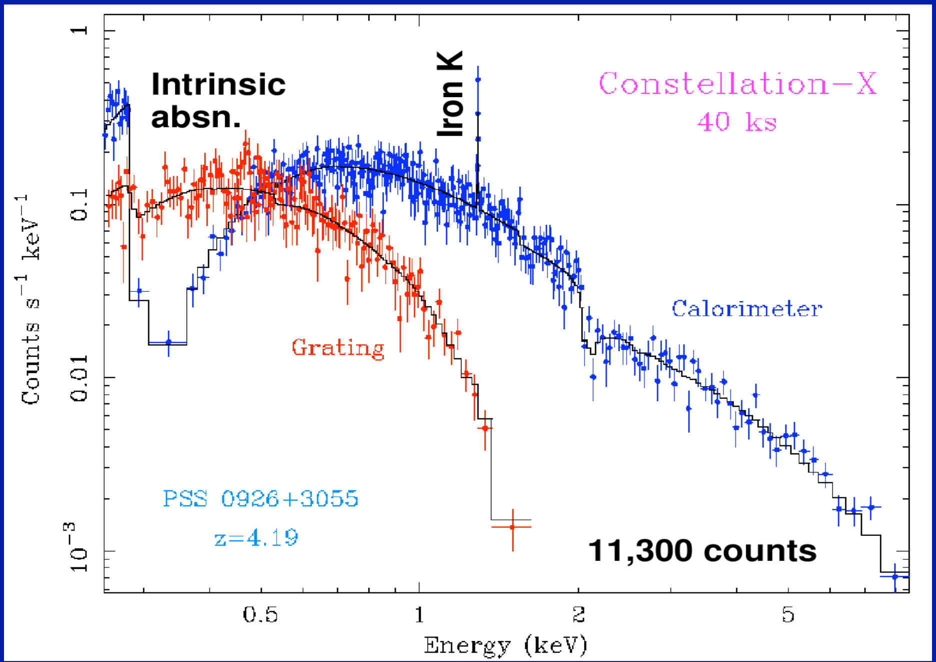
But current X-ray spectra greatly under-sample spectral complexity!

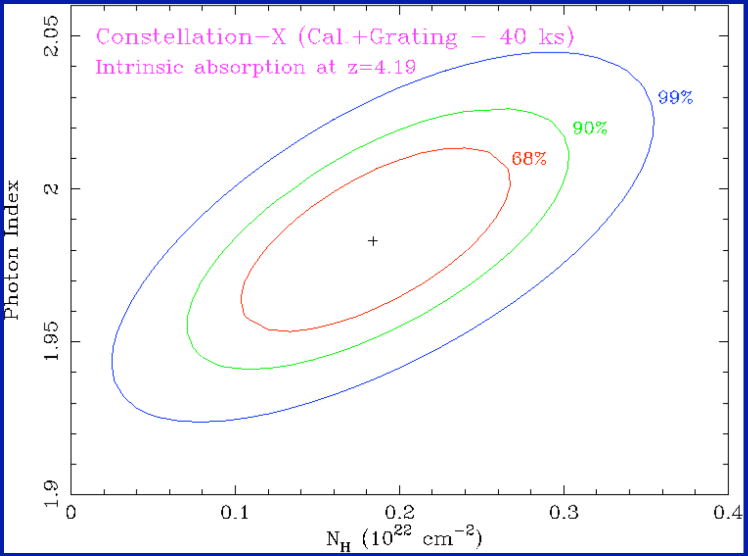


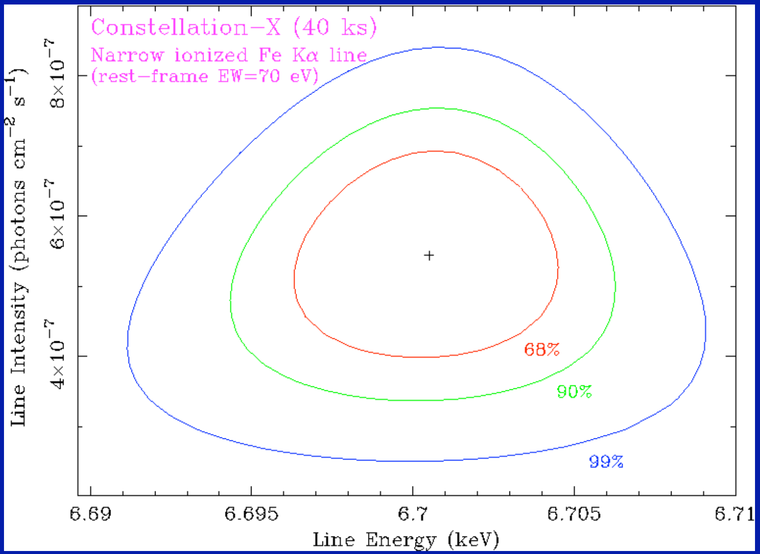


Prospects for Constellation-X and XEUS - 2

Simulated Constellation-X Spectra





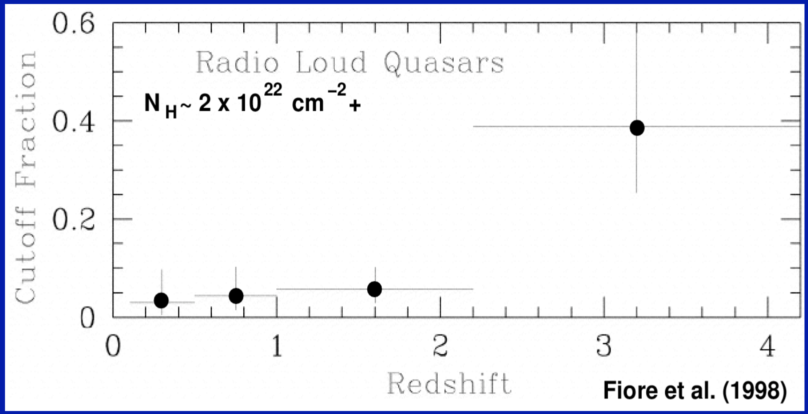


Con-X and XEUS would allow efficient spectroscopy and variability studies for many z > 4 AGNs.

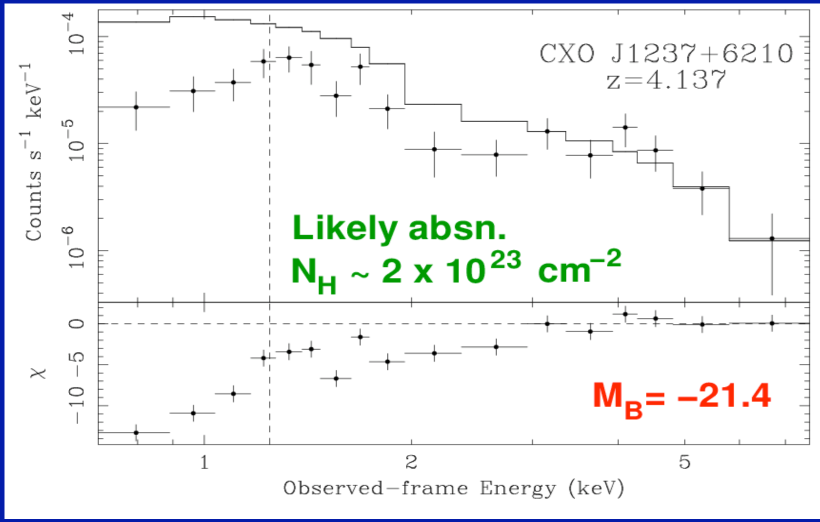
Absorption column and ionization, Fe K line properties, continuum spectral shape.

Prospects for Constellation-X and XEUS - 3

Fraction of RLQs with X-ray absorption appears to rise with redshift.



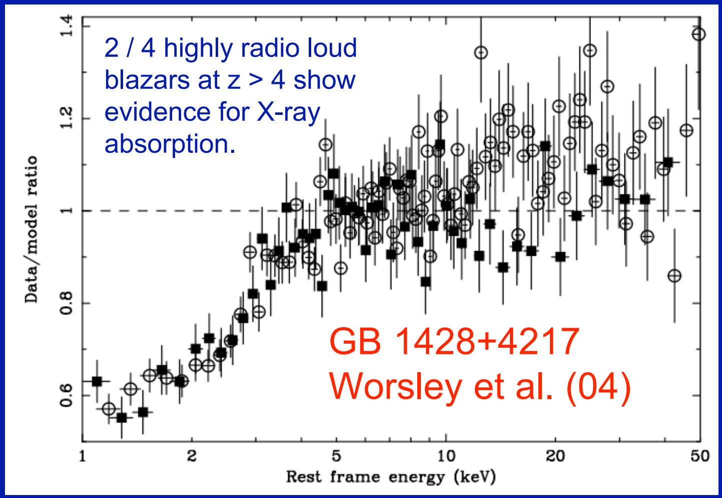
X-ray absorption in deep survey AGNs

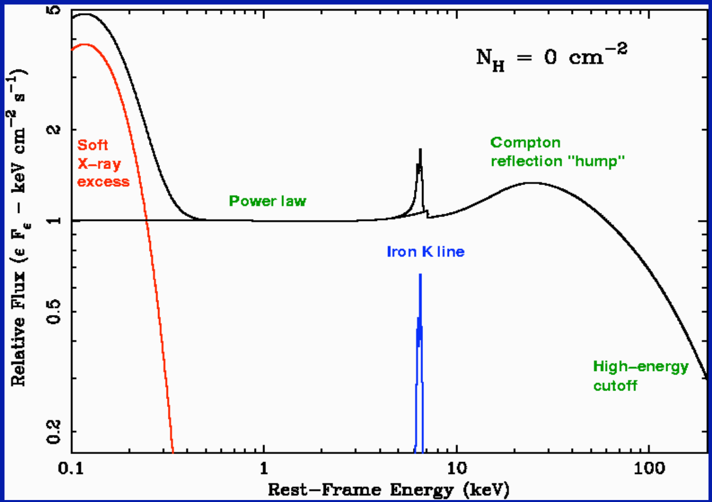


Absorbers associated with quasars' environments, but nature unclear.

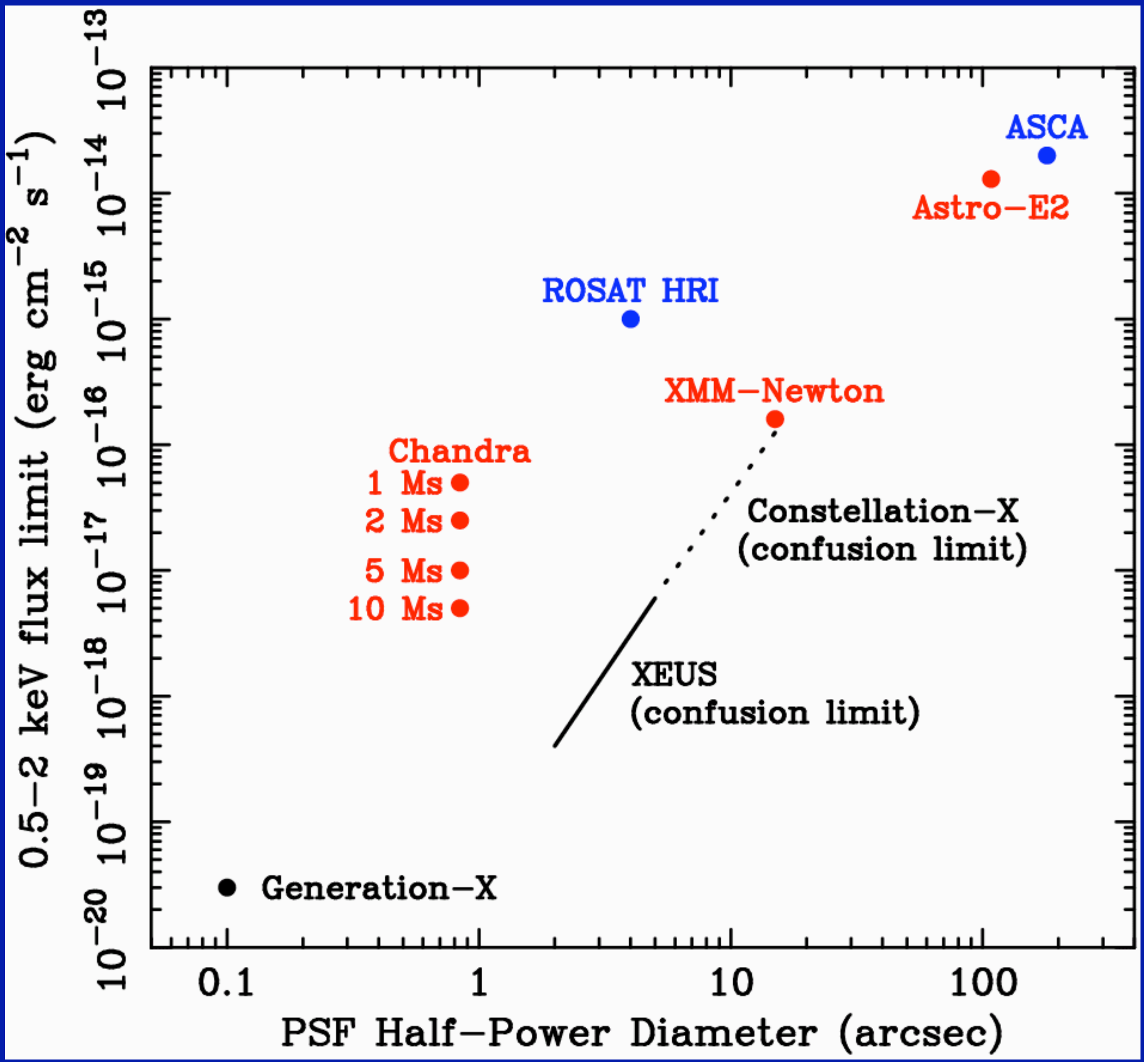
Circumnuclear, young host galaxy, entrained by jets?

Need high throughput and resolution at low energies for redshifted X-ray absorption constraints.





Prospects for Constellation-X and XEUS - 4

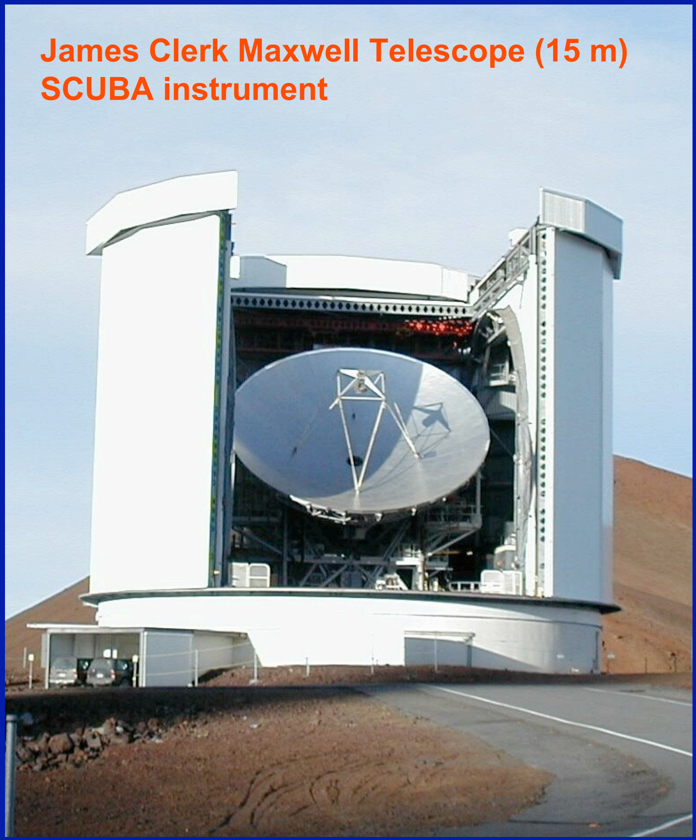


With sufficient angular resolution, a joint mission could be superb at surveys of the high-redshift universe.

Could efficiently reach Chandra Deep Field depths over large solid angles, greatly improving constraints on high-redshift AGN demography.

To reach the most sensitive fluxes, must avoid confusion with numerous starburst and normal galaxies.

Submillimeter Galaxies as Luminous, Distant Starbursts



Optical studies of high-redshift galaxies often miss those in which greatest number of stars forming.

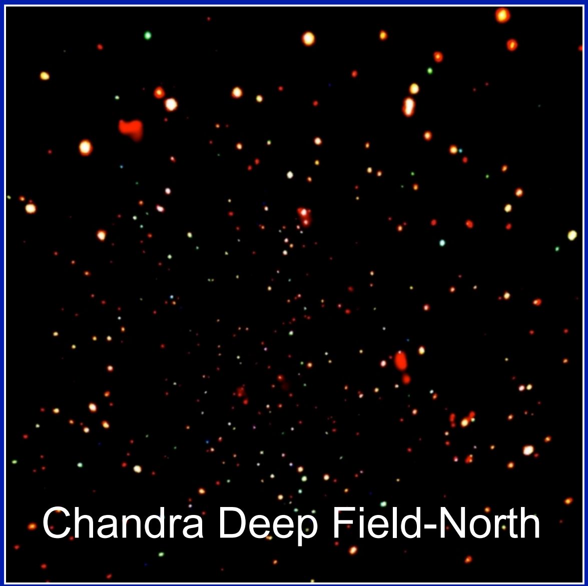
Dust-shrouded starbursts forming stars at ~ 1000 solar masses / year.

SCUBA sources at z ~ 1.5-3. About 1000 times more common at z ~ 2 as today.

Likely seeing the epoch of spheroid formation in massive galaxies.

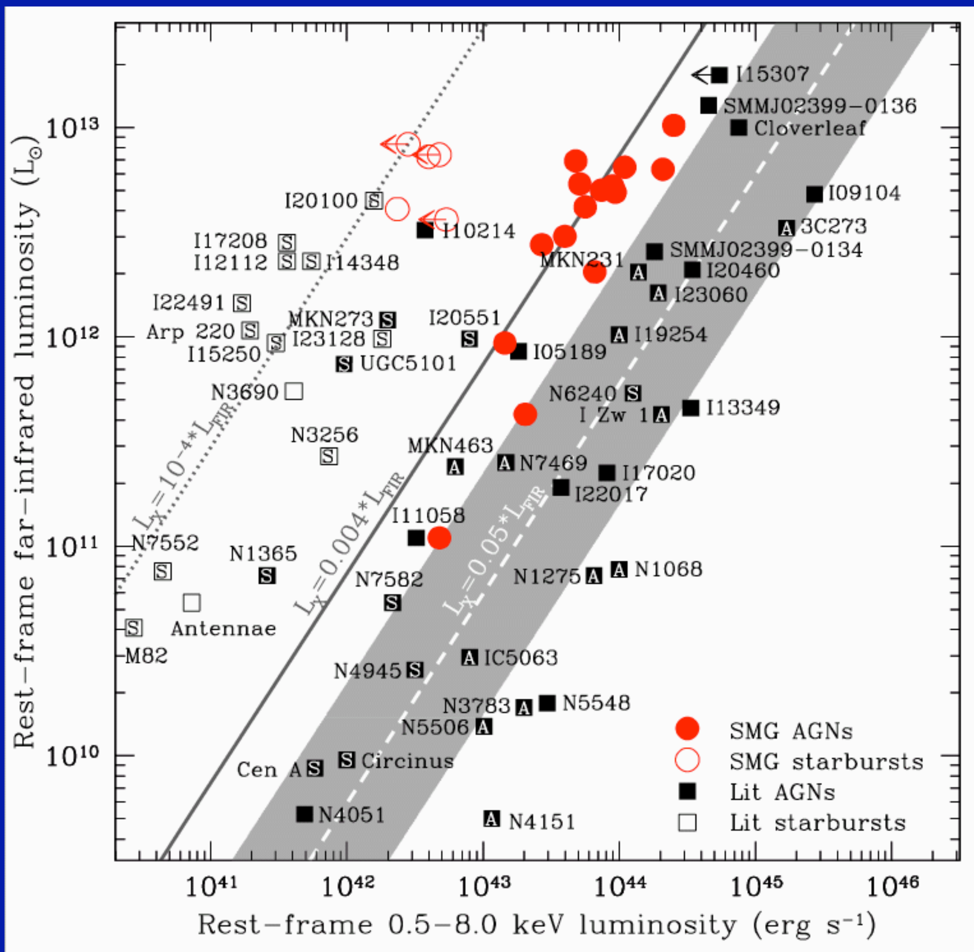
What fraction of these young, forming galaxies contain actively accreting black holes?

Detailed optical spectral classification difficult due to faintness, so deep X-ray surveys can play a critical role.


Chandra Deep Field-North

Deep X-ray Surveys Reveal the Active Galaxy Content of Submillimeter Galaxies

Far-infrared versus X-ray luminosity



Alexander et al. (2005)

Chapman et al. (2005) sample.

In exceptionally sensitive CDF-N, about 85% of submm galaxies with reliable positions now have Chandra detections.

Majority appear to contain moderate-luminosity AGN.

AGN fraction at least 40%.

Much higher than any other coeval galaxy population (usually ~ 5%).

AGNs usually appear obscured.

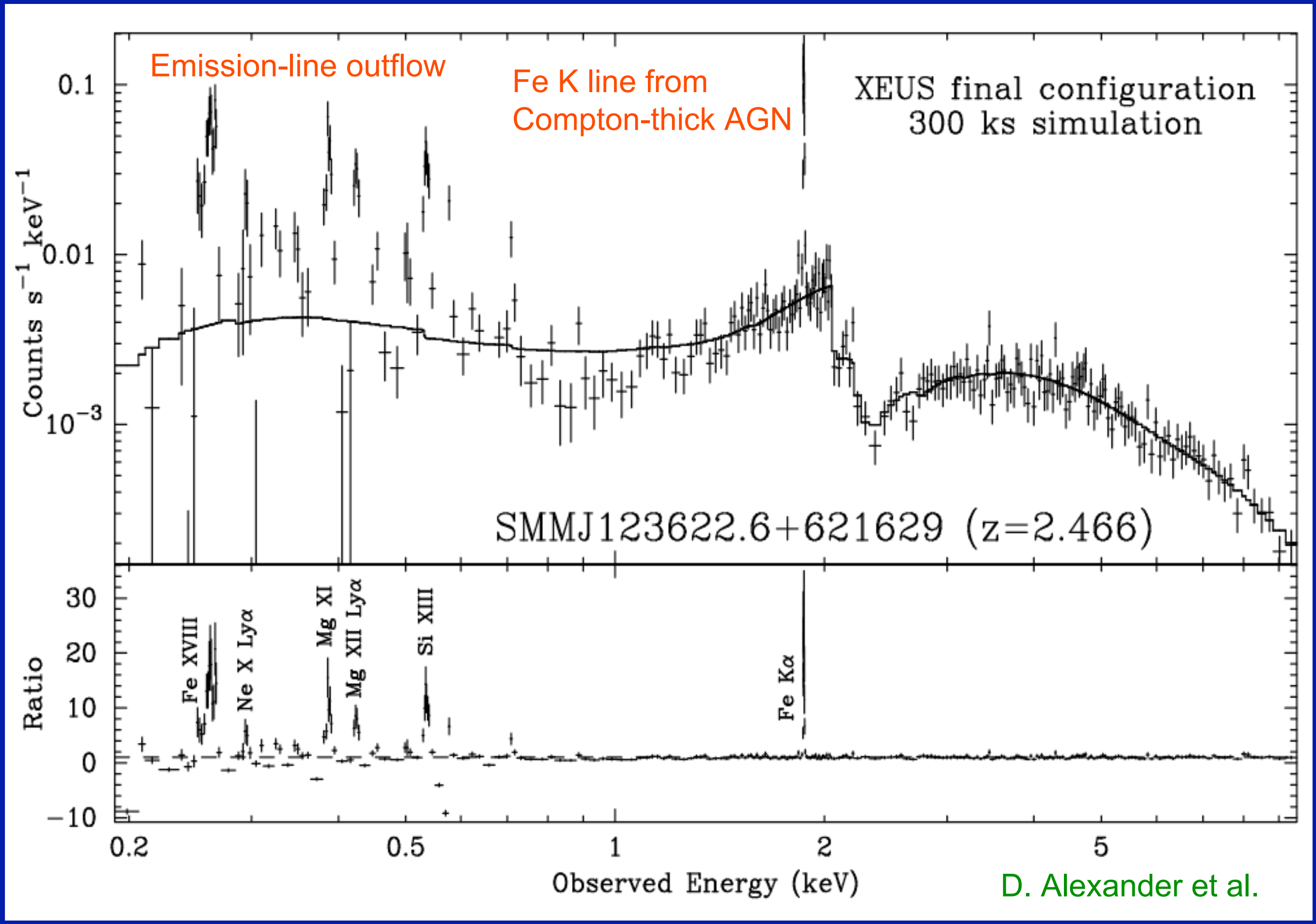
Supermassive black holes in submm galaxies almost continuously growing during observed phase of intense star formation.

Directly seeing simultaneous growth of supermassive black hole and spheroid? “Pre-quasars”

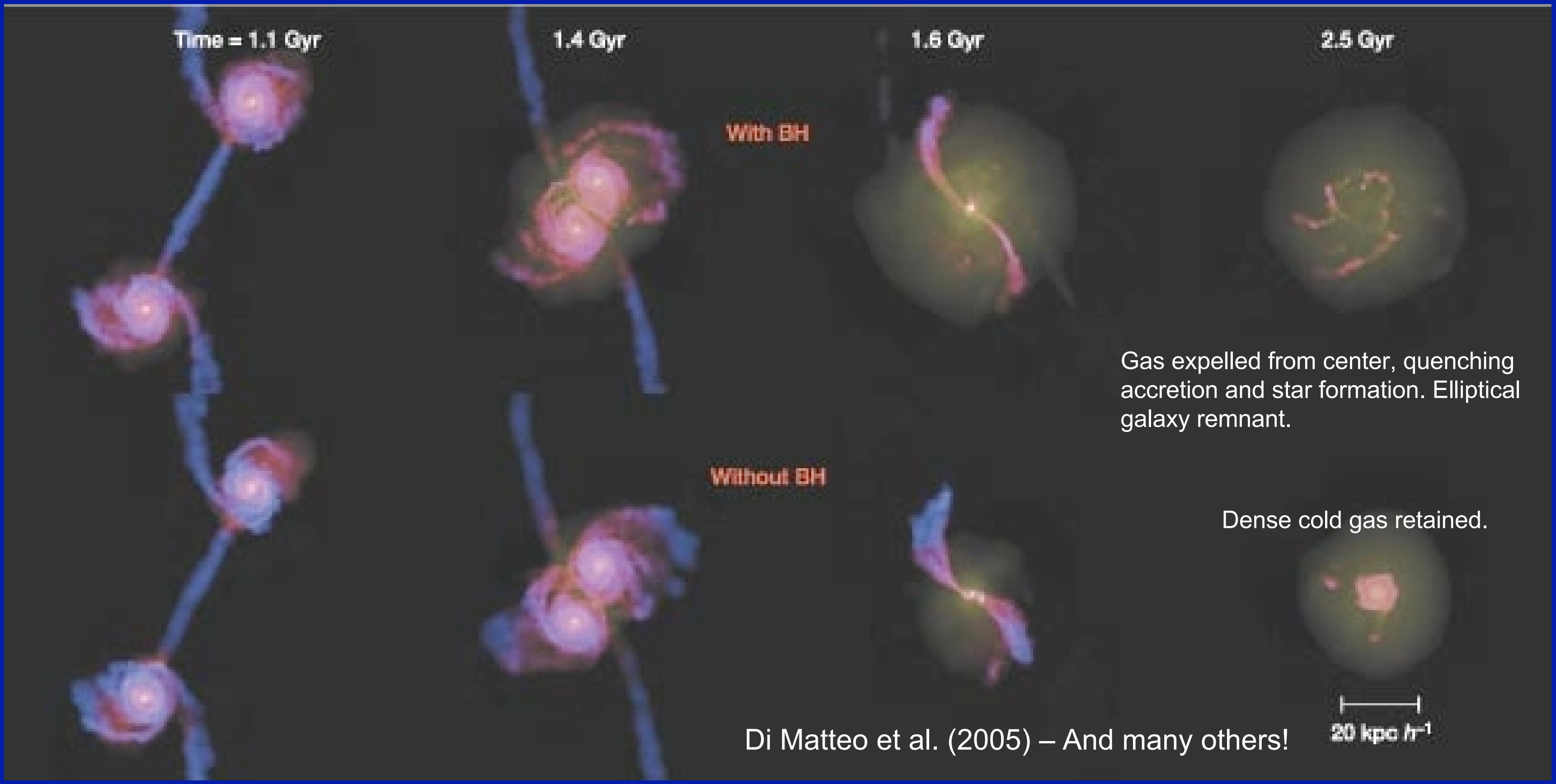
Prospects for Constellation-X and XEUS

X-ray spectral quality for individual sources is currently limited due to photon statistics.

XEUS Simulation for One of the Most Heavily Absorbed CDF-N Submm Galaxies



Relativistic X-ray Absorbing Outflows from Quasars?



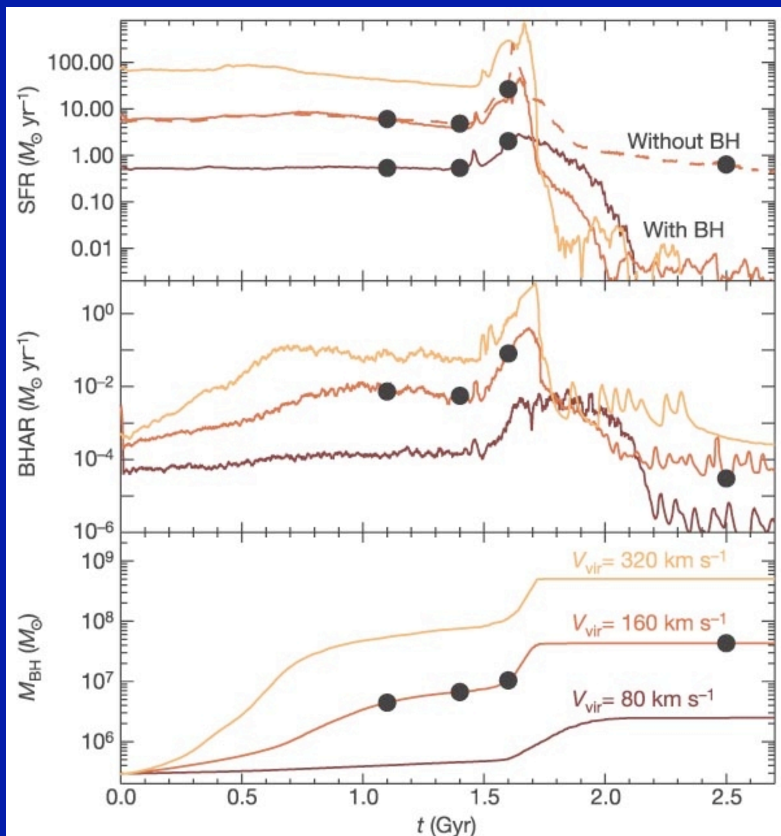
Quasar feedback can strongly affect black hole fueling and star formation in host galaxy.

Feedback likely from a wind, but details of feedback remain uncertain. Better feedback modeling needed.

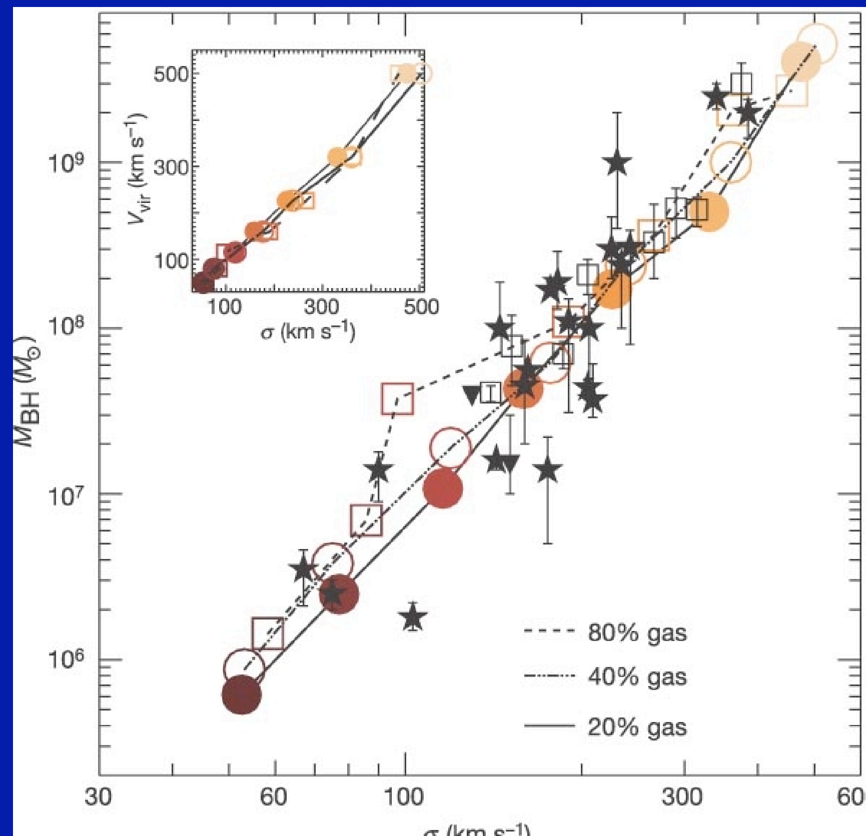
Perhaps can explain SMBH mass vs. bulge velocity dispersion.

Could hope to see gas being expelled via observations of X-ray absorption.

SMBH Mass vs. Bulge Velocity Dispersion from Quasar Feedback?

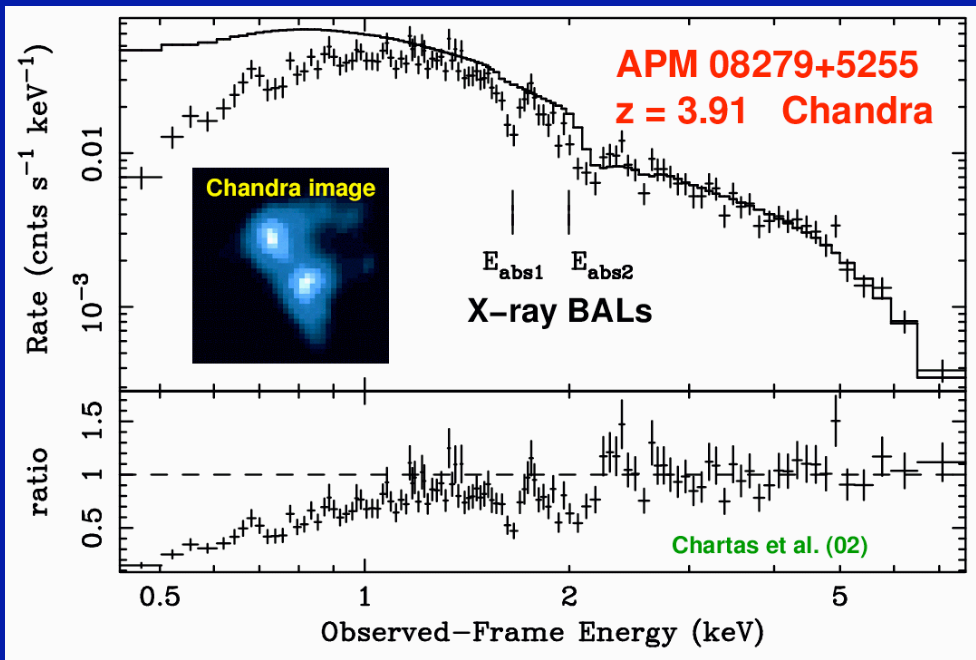


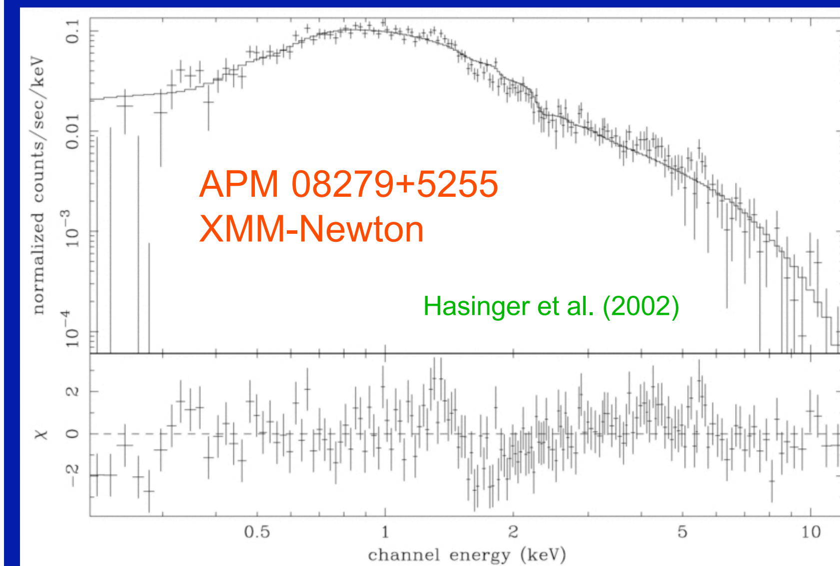
Quenching of star formation due to gas expulsion by quasar.



Observations versus output from merger simulation for varying total galaxy mass.

Possible X-ray Absorbing Outflow from APM 08279+5255





Fe K edge?

BAL quasar that is gravitationally lensed by factor of ~ 100.

Two apparent X-ray BALs detected at rest-frame energies of 8.1 and 9.8 keV. Also low-energy absorption.

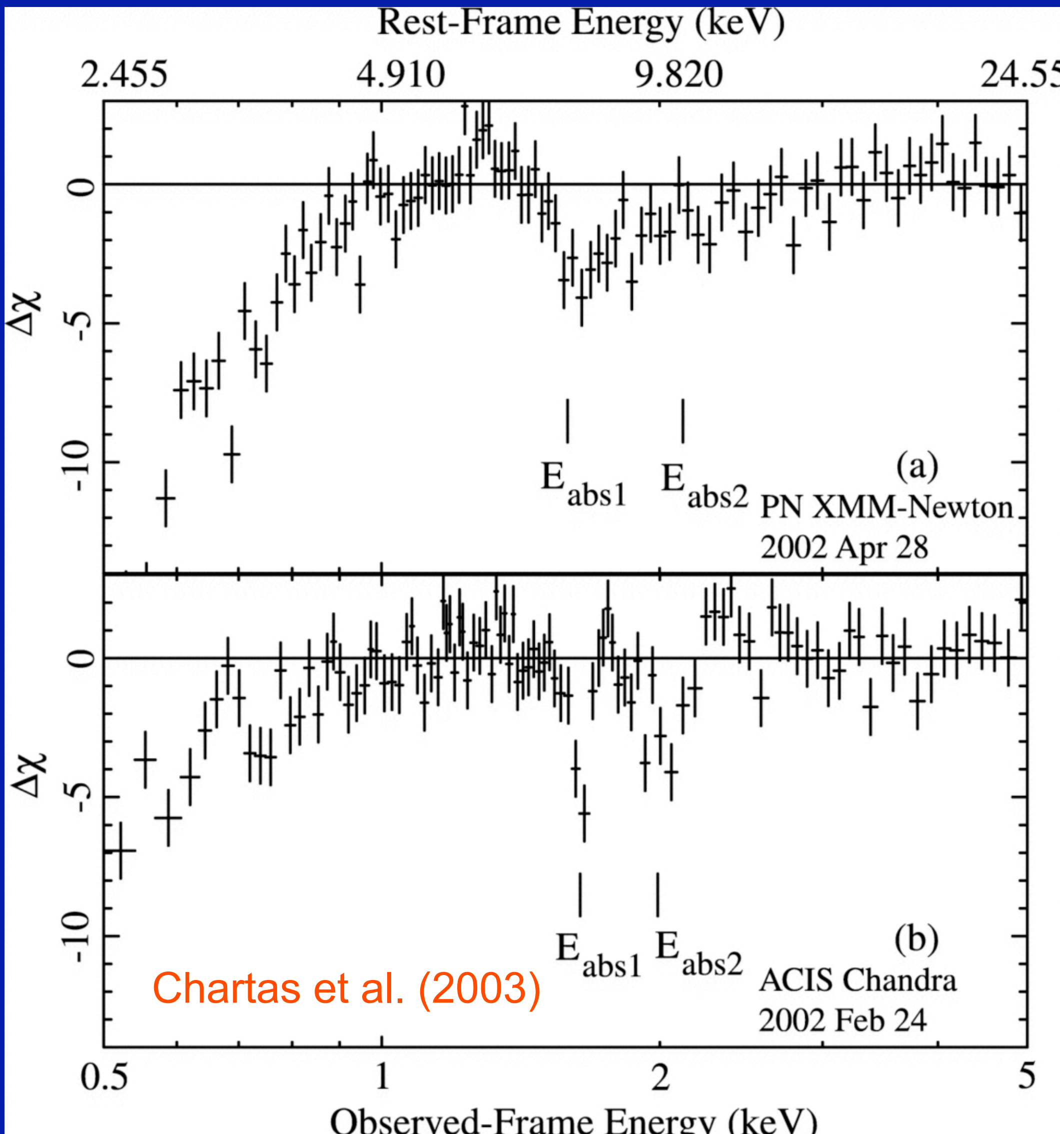
If due to Fe Kα then v ~ 0.2c and 0.4c. Much higher than UV absorption velocity.

Small launching radius probably required; shielding gas protecting UV absorber?

Apparent variability over 1.8 weeks (rest frame) between Chandra and XMM-Newton observations.

Better data clearly needed – long look proposed a few times, but no success yet.

Variability of APM 08279+5255 Absorption

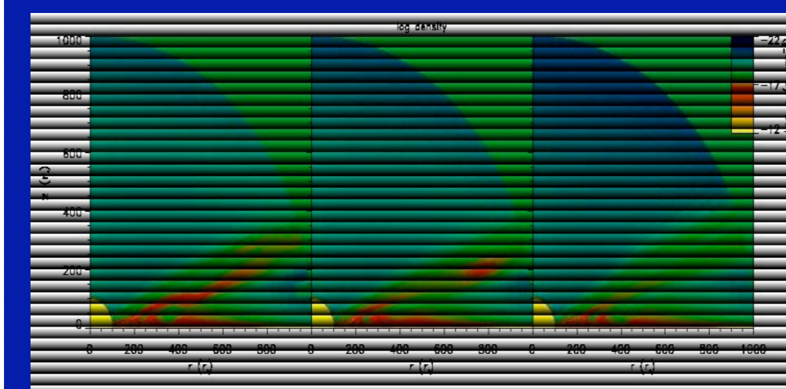


Chartas et al. (2003)

Two observations only separated by ~ 1.8 weeks in the rest frame!

The 2002 Feb data from Chandra cannot be fit acceptably with a basic edge model.

Strong apparent X-ray absorption variability would contrast with behavior in the UV.



Simulation variations over ~ 3 yr.

Proga et al. (2000)

Other Claimed Cases of Relativistic X-ray Absorbing Outflows from Quasars

PG 1211+143 – Pounds et al. (2003)

Disputed by Kaspi & Behar (2005) using same data, who claim that only need v ~ 3000 km/s.

Possibly some Galactic confusion as well – McKernan et al. (2005).

PG 1115+080 – Chartas et al. (2003)

Gravitationally lensed.

Photon statistics poorer than for APM 08279+5255.

New XMM-Newton data under analysis.

PDS 456 – Reeves et al. (2003)

Possibly some Galactic confusion as well – McKernan et al. (2005).

PG 0844+349 – Pounds et al. (2003)

Prospects for Constellation-X and XEUS

Con-X and XEUS can confirm (or refute) the claimed X-ray absorbing outflows.

Should be able to measure X-ray velocities and column densities, allowing assessment of wind kinetic power (as for local Seyferts). Potentially very high, capable of affecting galaxy evolution.

Need highest possible spectral resolution, since line profiles are likely complex (as for UV BALs).

Also can study time variability of X-ray absorber in detail.

PG 1115+080 Simulation for Constellation-X

Observed low-energy absorption may be forest of X-ray BALs